MARKET ASSESSMENT FOR LIGNIN BYPRODUCTS

Summary of Phase I Effort

Prepared for National Renewable Energy Laboratory
Under Consultant Agreement No. EXL-7-17478-01

June 15, 1998

J.E. Sinor Consultants Inc.

INTRODUCTION AND BACKGROUND

Under Consultant Agreement No. EXL-7-17478-01, the National Renewable Energy Laboratory requested that J.E. Sinor Consultants Inc. undertake the first phase of a market assessment for certain potential products that could be derived from lignin as a byproduct of ethanol production processes. These products include:

- Branched alkyl cyclohexyls
- Alkyl cyclohexyl methyl ethers
- Hydroxy alkyl cyclohexyls

It was believed that the first two of the products above could find use as gasoline additives or blending agents—as octane enhancers or as oxygenates, respectively.

It was agreed that the first-phase effort would consist of:

- Making a computer search of the literature
- Reviewing the results and ordering pertinent abstracts
- Searching for the complete reference for the best abstracts
- Making brief recommendations on the basis of the literature search

The above tasks were completed and discussed at a meeting with NREL personnel on June 12. This document formalizes the results discussed at that meeting.

RESULTS OF LITERATURE SEARCH

A computer search of several commercial databases was carried out using the key words octane, knocking and anitknock. Three hundred thirty-six titles were returned by the search. Abstracts were printed for the nine titles that seemed most pertinent.

By far the most valuable reference found is a 1958 publication—ASTM Special Technical Publication No. 225, *Knocking Characteristics of Pure Hydrocarbons*.

This book summarizes the results of 20 years of research sponsored by the American Petroleum Institute under API Research Project 45. Not only are octane numbers presented for 384 compounds, but also there are graphical correlations given which allow one to deduce the octane value of a compound based on its chemical structure alone.

CONCLUSIONS REGARDING CHEMICAL STRUCTURE

A review of the literature obtained makes it possible to draw the following immediate conclusions:

OCTANE NUMBERS FOR ALKYL CYCLOHEXYLS

Alkyl cyclohexyl hydrocarbons as a class do not have high enough octane numbers to be of interest as octane enhancers. The highest octane number listed for alkyl cyclohexyl compounds is less than 100. Moreover, the highest numbers result from the smallest molecules. Cyclohexane has a higher octane number than methylcyclohexane, which has a higher octane number than ethylcyclohexane, etc. Cyclohexane has an octane number of 83 by the Research Method and 77 by the Motor Method.

EFFECT OF CHEMICAL STRUCTURE

The lignin byproduct stream under consideration exits from the process with a high concentration of aromatic molecules. It had been proposed to hydrotreat this stream to convert the aromatics to cyclohexyls. In general, however, it is clear that the octane number goes down when aromatics are converted to cyclohexyls. Thus converting aromatics to cyclohexyls would be adding negative product value, as far as octane number is concerned.

The major path for cyclohexyl hydrocarbons in a petroleum refinery is to the reformer where they are dehydrogenated and converted to higher-value aromatics.

It is concluded that alkyl cyclohexyl hydrocarbons as a class are not suited to be octane enhancers for modern-day gasoline. Alkyl aromatic compounds have much better octane numbers.

ETHERS

Ethers offer two potential benefits to gasoline: they can provide enhanced octane value and they can provide oxygen (required for reformulated gasoline in the nine worst air-quality regions).

Methyl phenyl ether has a motor octane number of 96 and a blending octane number of 130 according to one source, and research/motor octane numbers of 115/96 according to another source.

Although ethers with two functional groups containing two oxygens (such as dimethoxybenzene), would appear to have more oxygenate value than monofunction ethers, it is likely they would have too high a boiling point. If large amounts are to be used as a blending agent, it would have to have a boiling point less than the T_{90} of gasoline (165°C).

Monofunctional aromatic ethers could be viable candidates for further evaluation.

METAL COMPLEXES

It has been suggested that di-hydroxy compounds with the proper molecular geometry could serve as complexing agents for various metals that have been found to have antiknock benefits. However, EPA rules require that no heavy metals be added to gasoline. Any metal would be considered a new substance in gasoline and would require an EPA waiver. The waiver requires complete testing for toxicity and carcinogenicity and could take years and cost millions. Metal complexes are not considered to be a viable product option.

CONCLUSIONS REGARDING MARKETS FOR AROMATICS

The original logic for pursuing cyclohexyl compounds rather than aromatics was the idea that aromatics will be removed from gasoline in the future. That, however, is a considerable overstatement of the situation. The only federal limit at present is a limitation on benzene (1 percent maximum). The average total aromatics content of U.S. gasoline is around 30 to 35 percent. In California the Phase II Reformulated Gasoline Program limits total aromatics to 25 percent. Although it is conceivable, and perhaps even likely, that aromatics levels will be reduced in the future, it is highly unlikely that they will be reduced to anywhere near zero. Even if all U.S. gasoline is capped at 25 percent or less aromatics, the market for aromatics in gasoline will remain huge. What is likely to happen is a gradual replacement of less-desirable aromatics with more-desirable aromatics. Toluene offers the highest octane number at around 120.

A lignin-derived aromatic that offered a high octane number plus an appreciable oxygen content could be valued quite highly. Benzene price levels relative to gasoline have dropped in the past few years because of the California and federal limits forcing refiners to remove benzene from the gasoline pool. However, toluene has not experienced a comparable drop in price, and refining industry analysts do not expect it to do so.

The overall conclusion is that aromatic gasoline components with desirable characteristics will continue to find a large market at relatively attractive price levels. Lignin byproduct development efforts should be refocused on such products.

NOTES FOR LIGNIN BYPRODUCTS MEETING

June 12, 1998

J. E. Sinor

- Preliminary literature search finds ASTM 1958 data book on knocking tendencies of hydrocarbons. Data on 384 compounds.
- Computer search yields 336 titles.
- General conclusion that cyclohexyls are not suitable as octane enhancers.
- In general, octane number is decreased when converting aromatics to cyclohexyls.
- The major path for cyclohexyls in the refinery is to the reformer where they are dehydrogenated and converted to higher-octane aromatics.
- Converting aromatics to cyclohexyls would be adding negative product value, as far as octane value is concerned.
- Market price for cyclohexane is high because it is high-purity nylon synthesis grade (99.5% pure, no benzene) made from benzene. Cannot separate cyclohexane by distillation (from crude) because of too many compounds with close boiling points.
- Benzene has dropped in relative market price due to the specific percentage limit on benzene in reformulated gasoline. However, refining industry analysts do not believe that toluene will lose value in the future as an octane enhancer. Therefore toluene and MTBE should be suitable benchmarks for the octane value of aromatics and ethers, respectively.
- Boiling point must be less than T_{90} of gasoline (165 C).
- EPA - CA comm. - aromatic limit - 20% now

RFG - aromatic limit
- benzene limit - prices dropping
- Toluene demand still up
- bust of aromatics

Figure / Table from:
May, 1958
ASTM Special Technical Publication No. 225
Knocking Characteristics of Pure Hydrocarbons

ASTM OCTANE NUMBERS -- NAPHTHENES

Hydrocarbon	Description Number	Research Method				
					20% Blend (F)	Blending Octane Number (G)
	ml TEL Added	0.0	1.0	3.0	0.0	0.0
CYCLOPROPANES						
Methylcyclopropane	262	+0.2	-	+0.4y	-	-
Ethylcyclopropane	299	+0.2	-	+0.7	71.0	115
		+0.3MT	-	+0.6MT	71.2MT	116MT
1,1-Dimethylcyclopropane	111S,111A	-	-	-	71.2b	116b
1,2-Dimethylcyclopropane (cis)	251,251A	+0.4,+0.3bMT	-	+0.7bMT	72.4	122
1,2-Dimethylcyclopropane (trans)	250S	+0.4MT	-	+0.7MT	71.8MT	119MT
Isopropylcyclopropane	306	+0.02	-	+0.2	70.1	110
1,1,2-Trimethylcyclopropane	177	+1.5	-	>+3.0	74.5	132
1,1-Diethylcyclopropane	123S,123A	-	-	-	70.8b	114b
1,1,2,2-Tetramethylcyclopropane	227	+0.5	-	+1.7	75.6	138
Isopropenylcyclopropane	307	94.4,94.5MT	-	97.0,97.2MT	82.4	172
CYCLOBUTANES						
Ethylcyclobutane	162S	41.1	-	-	53.9	30
CYCLOPENTANES						
Cyclopentane	63,63A	+0.1b	-	+0.9b	76.2	141
Methylcyclopentane	66	91.3	99.5	+0.5	69.4	107
Ethylcyclopentane	55	67.2	72.3	79.5	62.9	74
1,1-Dimethylcyclopentane	220	92.3	-	+0.9	67.3	96
1,3-Dimethylcyclopentane (cis)	178,178A	79.2	-	91.2	67.7b	98b
1,3-Dimethylcyclopentane (trans)	179	80.6	-	93.2	66.1	90
n-Propylcyclopentane	18,18A	31.2	43.1	59.8	53.3b	26b
iso-Propylcyclopentane	19	81.1	89.6	94.3	64.6	83
1-Methyl-3-ethylcyclopentane	230,231	57.6	-	79.2	-	-
1,1,3-Trimethylcyclopentane	134	87.7	-	+0.1	66.8	94
1,2,4-Trimethylcyclopentane (cis, trans,cis)	215	-	-	-	64.0	80
1,2,4-Trimethylcyclopentane (cis, cis,trans)	217S	89.2MT	-	98.3MT	-	-
n-Butylcyclopentane	170	(-3)	-	29.6	47.2	(-4)
iso-Butylcyclopentane	110	33.4	47.9	59.2	54.8	34
tert-Butylcyclopentane	124A,124S	-	-	-	70.5	112
1,2-Diethylcyclopentane (trans concentrate)	125S	-	-	-	-	-
1,1,2,4-Tetramethylcyclopentane	327S	96.2MT	-	+0.3MT	-	-
n-Decylcyclopentane	205	-	-	-	35.0	(-65)
Vinylcyclopentane	279	69.3	-	82.9	64.2	81
Ethylidenecyclopentane	280	82.4	-	89.7	77.6	148
Allylcyclopentane	289	52.1	-	75.6	60.0	60
CYCLOHEXANES						
Cyclohexane	10	83.0	92.9	97.4	69.9	110
Methylcyclohexane	11	74.8	83.5	88.2	68.8	104
Ethylcyclohexane	2	45.6	54.0	65.1	56.6	43
1,1-Dimethylcyclohexane	135	87.3	-	98.0	67.0	95
1,2-Dimethylcyclohexane (cis)	25	80.9	89.2	94.3	64.9	84
1,2-Dimethylcyclohexane (trans)	24	80.9	89.8	94.5	65.0	85
1,3-Dimethylcyclohexane (cis)	30	71.7	-	-	-	-
1,3-Dimethylcyclohexane (trans)	21	66.9	75.7	83.5	61.3	67
1,4-Dimethylcyclohexane (cis)	26	67.2	78.0	84.7	61.6	68
1,4-Dimethylcyclohexane (trans)	22	68.3	75.1	82.8	60.7	64
n-Propylcyclohexane	67	17.8	25.6	42.8	-	-
iso-Propylcyclohexane	34	62.8	70.1	79.6	60.4	62
1-Methyl-1-ethylcyclohexane	287	68.7	-	85.7	60.9	64
1,1,2-Trimethylcyclohexane	323	95.7	-	+0.4	-	-
1,1,3-Trimethylcyclohexane	51	81.3	89.5	94.8	64.9	85
1,2,3-Trimethylcyclohexane (cis, trans,cis)	324	83.4	-	95.7	-	-
1,2,3-Trimethylcyclohexane (cis, cis,trans)	325	86.2	-	96.9	-	-
1,2,4-Trimethylcyclohexane (cis, trans,trans)	300	73.0,72.8MT	-	88.0	62.4	72

For explanatory notes see page 68.

ASTM OCTANE NUMBERS -- NAPHTHENES

Motor Method					Hydrocarbon	Description Number
			20% Blend (F)	Blending Octane Number (G)		
0.0	1.0	3.0	0.0	0.0	. . . . . ml TEL Added	
					CYCLOPROPANES	
81.2	-	87.2y	-	-	Methylcyclopropane	262
83.9	-	87.8	70.0	110	Ethylcyclopropane	299
83.7MT	-	87.7MT	69.6MT	108MT		
-	-	-	69.6b	108b	1,1-Dimethylcyclopropane	111S,111A
85.7,82.9bMT	-	86.6bMT	71.3	116	1,2-Dimethylcyclopropane (cis)	251,251A
-	-	86.9MT	-	-	1,2-Dimethylcyclopropane (trans)	250S
88.1	-	93.0	69.2	106	Isopropylcyclopropane	306
87.8	-	93.0	72.5	122	1,1,2-Trimethylcyclopropane	177
-	-	-	69.6b	108b	1,1-Diethylcyclopropane	123S,123A
90.1	-	96.2	74.0	130	1,1,2,2-Tetramethylcyclopropane	227
74.9,74.8MT	-	76.3,76.6MT	75.9	140	Isopropenylcyclopropane	307
					CYCLOBUTANES	
63.9	-	-	60.3	62	Ethylcyclobutane	162S
					CYCLOPENTANES	
85.0,84.8b	91.4	95.2	76.2	141	Cyclopentane	63,63A
80.0	89.4	93.0	67.8	99	Methylcyclopentane	66
61.2	72.7	80.7	60.6	63	Ethylcyclopentane	55
89.3	-	+0.1	68.3	102	1,1-Dimethylcyclopentane	220
73.1	-	86.8	63.1	75	1,3-Dimethylcyclopentane (cis)	178,178A
72.6	-	87.1	63.0	75	1,3-Dimethylcyclopentane (trans)	179
28.1	43.3	60.5	53.4b	27b	n-Propylcyclopentane	18,18A
76.2	85.7	89.4	64.2	81	iso-Propylcyclopentane	19
59.8	-	79.6	-	-	1-Methyl-3-ethylcyclopentane	230,231
83.5	-	95.6	66.9	94	1,1,3-Trimethylcyclopentane	134
-	-	-	65.2	86	1,2,4-Trimethylcyclopentane (cis,trans,cis)	215
79.5MT	-	-	-	-	1,2,4-Trimethylcyclopentane (cis,cis,trans)	217S
(-2)	-	36.7	49.0	5	n-Butylcyclopentane	170
28.2	40.6	58.1	55.3	36	iso-Butylcyclopentane	110
-	-	-	70.3	112	tert-Butylcyclopentane	124A,124S
-	-	-	57.0	45	1,2-Diethylcyclopentane (trans concentrate)	125S
88.0MT	-	98.1MT	-	-	1,1,2,4-Tetramethylcyclopentane	327S
-	-	-	28.3	(-98)	n-Decylcyclopentane	205S
54.3	-	68.5	61.9	70	Vinylcyclopentane	279
66.6	-	72.3	72.3	122	Ethylidenecyclopentane	280
45.6	-	63.6	59.5	58	Allylcyclopentane	289
					CYCLOHEXANES	
77.2	85.4	87.3	67.4	97	Cyclohexane	10
71.1	82.0	86.2	64.3	84	Methylcyclohexane	11
40.8	52.3	65.4	55.9	40	Ethylcyclohexane	2
85.9	-	95.7	66.9	94	1,1-Dimethylcyclohexane	135
78.6	87.2	90.7	64.4	82	1,2-Dimethylcyclohexane (cis)	25
78.7	87.3	90.8	64.8	84	1,2-Dimethylcyclohexane (trans)	24
71.0	-	-	-	-	1,3-Dimethylcyclohexane (cis)	30
64.2	78.3	83.8	60.9	64	1,3-Dimethylcyclohexane (trans)	21
68.2	80.0	85.0	61.2	66	1,4-Dimethylcyclohexane (cis)	26
62.2	77.4	83.4	59.3	59	1,4-Dimethylcyclohexane (trans)	22
14.0	29.4	47.7	-	-	n-Propylcyclohexane	67
61.1	74.3	81.4	60.4	62	iso-Propylcyclohexane	34
76.7	-	88.6	62.4	72	1-Methyl-1-ethylcyclohexane	287
87.7	-	97.0	-	-	1,1,2-Trimethylcyclohexane	323
82.6	91.2	95.8	66.4	92	1,1,3-Trimethylcyclohexane	51
81.0	-	90.6	-	-	1,2,3-Trimethylcyclohexane (cis, trans,cis)	324
82.5	-	91.0	-	-	1,2,3-Trimethylcyclohexane (cis, cis,trans)	325
74.6,74.0MT	-	87.9	63.3	77	1,2,4-Trimethylcyclohexane (cis, trans,trans)	300

For explanatory notes see page 68.

ASTM OCTANE NUMBERS -- NAPHTHENES (Cont'd)

Hydrocarbon	Description Number	Research Method				
					20% Blend (F)	Blending Octane Number (G)
	ml TEL Added	0.0	1.0	3.0	0.0	0.0
CYCLOHEXANES (Cont'd.)						
1,3,5-Trimethylcyclohexane (cis)	254	59.1	-	78.0	59.9	60
1,3,5-Trimethylcyclohexane (trans)	290S	68.5	-	83.9	-	-
n-Butylcyclohexane	101	-	-	22.5	46.4	(-8)
iso-Butylcyclohexane	137	33.7	42.4	56.4	55.7	38
sec-Butylcyclohexane	131	51.0	59.5	71.2	56.8	44
tert-Butylcyclohexane	109	98.5	+0.2	+0.8	71.1	116
1-Methyl-2-n-propylcyclohexane (cis)	320	30.4	-	56.0	52.8	24
1-Methyl-2-n-propylcyclohexane (trans)	321	29.4	-	54.8	-	-
1-Methyl-4-isopropylcyclohexane (cis)	274	63.4	-	-	60.7	64
1-Methyl-4-isopropylcyclohexane (trans)	275	-	-	79.1	60.2	61
1-Methyl-4-isopropylcyclohexane (cis-trans)	69	62.3	70.2	78.5	-	-
tert-Amylcyclohexane	232	90.4	-	98.8	66.6	93
1,2,4-Trimethyl-4-isopropylcyclohexane	333	96.0	-	+0.3	-	-
n-Decylcyclohexane	206S	-	-	-	42.5	(-28)
Vinylcyclohexane	270	64.3	-	79.9	62.5	72
Ethylidenecyclohexane	288	83.0	-	90.2	-	-
CYCLOHEPTANES AND HIGHER						
Cycloheptane	259S,259A	38.7MT,38.9b	-	59.8b	56.3b	42b
Ethylcycloheptane	326S	28.0MT	-	50.0MT	-	-
Cyclo-octane	245,245A	69.9MT,72.0bMT	-	-	64.0	80
BICYCLIC COMPOUNDS						
Dicyclopropylmethane	313S	95.1MT	-	98.6MT	-	-
Cyclopentylcyclopentane	204	9.7	-	30.6	51.9	20
Bicyclo(2.2.1)heptane (N)	72	-	-	-	58.9	54
2-Ethylbicyclo(2.2.1)heptane	97	51.9	60.2	71.5	57.7	48
Hydrindan (cis)	129A,129AA	70.0	-	87.7	63.4b	77b
Hydrindan (trans)	133	58.5	-	72.6	61.6	68
Pinane	71	77.7	85.7	91.3	59.8	59
Decahydronaphthalene (cis)	202	-	-	-	54.7	34
Decahydronaphthalene (trans)	201	-	-	-	56.3	42

For explanatory notes see page 68.

ASTM OCTANE NUMBERS -- NAPHTHENES (Cont'd)

Motor Method						Description Number
			20% Blend (F)	Blending Octane Number (G)		
0.0	1.0	3.0	0.0	0.0	. . . . . ml TEL Added	
					CYCLOHEXANES (Cont'd.)	
56.4	-	79.4	59.7	58	1,3,5-Trimethylcyclohexane (cis)	254
70.1	-	-	-	-	1,3,5-Trimethylcyclohexane (trans)	290S
-	4.4	25.3	47.3	(-4)	n-Butylcyclohexane	101
28.9	40.3	58.3	55.7	38	iso-Butylcyclohexane	137
55.2	64.2	74.6	59.6	58	sec-Butylcyclohexane	131
89.2	92.3	96.3	68.1	100	tert-Butylcyclohexane	109
38.8	-	69.0	57.0	45	1-Methyl-2-n-propylcyclohexane (cis)	320
39.2,38.4MT	-	67.9	-	-	1-Methyl-2-n-propylcyclohexane (trans)	321
-	-	-	60.5	63	1-Methyl-4-isopropylcyclohexane (cis)	274
62.9	-	80.2	60.4	62	1-Methyl-4-isopropylcyclohexane (trans)	275
60.5	71.4	81.4	-	-	1-Methyl-4-isopropylcyclohexane (cis-trans)	69
85.1	-	92.2	66.5	92	tert-Amylcyclohexane	232
90.0	-	99.7	-	-	1,2,4-Trimethyl-4-isopropylcyclohexane	333
-	-	-	36.4	(-58)	n-Decylcyclohexane	206S
53.4	-	67.3	60.6	63	Vinylcyclohexane	270
70.6	-	75.9	-	-	Ethylidenecyclohexane	288
					CYCLOHEPTANES AND HIGHER	
39.7MT,40.8b	-	65.3b	56.0b	40b	Cycloheptane	259S,259A
30.0MT	-	60.1MT	-	-	Ethylcycloheptane	326S
58.5, 57.8b	-	-	61.9	70	Cyclo-octane	245,245A
					BICYCLIC COMPOUNDS	
72.1MT	-	-	-	-	Dicyclopropylmethane	313S
9.7	-	43.1	51.5	18	Cyclopentylcyclopentane	204
-	-	-	58.5	52	Bicyclo(2.2.1)heptane (N)	72
49.7	60.6	70.9	59.2	56	2-Ethylbicyclo(2.2.1)heptane	97
64.1	-	77.0	62.2b	71b	Hydrindan (cis)	129A,129AA
48.8	-	66.7	58.1	50	Hydrindan (trans)	133
65.9	75.4	78.8	60.5	62	Pinane	71
-	-	-	54.7	34	Decahydronaphthalene (cis)	202
-	-	-	55.2	36	Decahydronaphthalene (trans)	201

For explanatory notes see page 68.

ASTM OCTANE NUMBERS -- MISCELLANEOUS

Fuel	Description Number	Research Method				
	ml TEL Added	0.0	1.0	3.0	20% Blend (F) 0.0	Blending Octane Number (G) 0.0
Hydrogen	dP	92±2 dP	-	-	-	-
OXYGEN COMPOUNDS						
Carbon Monoxide	dP	>+6.0 dP	-	-	-	-
Cyclopentanone	257	+0.1	-	+0.2	79.1	156
Cyclohexanone	258	+0.1	-	+0.8	74.4	132
Methyl tert-butyl ether	77	+4.5	-	-	77.5	148
Di-iso-propyl ether	E	+0.2	+1.0	-	69.1	105
Methyl phenyl ether	102	>+3	-	-	76.4	142
Ethyl phenyl ether	144S	-	-	-	78.7	154
Methyl 2-tolyl ether	141S	-	-	-	72.7	124
Methyl 3-tolyl ether	142S	-	-	-	77.1	148
Methyl 4-tolyl ether	143S	-	-	-	81.2	166
Furan	154	+1.0	-	+0.9	85.9	190
2-Methylfuran	193	+0.2	-	+0.4	89.8	209
2,5-Dimethylfuran	89	+0.1	-	-	91.0	215
Tetrahydrofuran	155	72.9	-	83.4	65.9	90
2-Methyltetrahydrofuran	197	-	-	-	66.3	92
2,5-Dimethyltetrahydrofuran (cis & trans)	90	92.2	-	99.6	69.2	106
Tetrahydropyran	76	52.2	-	71.0	-	-
Dihydropyran	75	66.5	73.3	79.9	67.9	100
NITROGEN COMPOUNDS						
alpha-Picoline (B)	80	-	-	-	74.2	131
Pyrrole (B)	84	-	-	-	81.5j	168
Pyrrolidine	224	90.9	-	90.9	93.2	226
2-Methylpiperidine	192	75.2	-	81.7	74.4	132

For explanatory notes see page 68.

ASTM OCTANE NUMBERS -- MISCELLANEOUS

Motor Method					Fuel	Description Number
0.0	1.0	3.0	20% Blend (F) 0.0	Blending Octane Number (G) 0.0	..... ml TEL Added	
-	-	-	-	-	Hydrogen	dP
					OXYGEN COMPOUNDS	
-	-	-	-	-	Carbon Monoxide	dP
89.4	-	91.9	72.9	124	Cyclopentanone	257
87.7	-	94.6	72.5	122	Cyclohexanone	258
+0.1	+3.0	+4.9	77.1	146	Methyl tert-butyl ether	77
98.9	+1.0	+3.4	71.4	117	Di-iso-propyl ether	E
96.0	96.4	96.7	73.9	130	Methyl phenyl ether	102
-	-	-	77.5	148	Ethyl phenyl ether	144S
-	-	-	69.9	110	Methyl 2-tolyl ether	141S
-	-	-	75.4	137	Methyl 3-tolyl ether	142S
-	-	-	77.7	148	Methyl 4-tolyl ether	143S
91.6	-	87.9	81.4	167	Furan	154
86.1	-	88.2	84.0	180	2-Methylfuran	193
88.1	-	-	83.5	178	2,5-Dimethylfuran	89
64.8	-	74.1	65.2	86	Tetrahydrofuran	155
-	-	-	66.2	91	2-Methyltetrahydrofuran	197
80.2	-	90.3	67.6	98	2,5-Dimethyltetrahydrofuran (cis & trans)	90
35.4	45.3	58.3	52.8	24	Tetrahydropyran	76
48.7	54.7	60.8	64.6	83	Dihydropyran	75
					NITROGEN COMPOUNDS	
+3.9	-	-	70.5	112	alpha-Picoline (B)	80
-	-	-	73.6j	128	Pyrrole (B)	84
66.2	-	66.8	79.7	158	Pyrrolidine	224
46.7	-	60.0	65.7	88	2-Methylpiperidine	192

For explanatory notes see page 68.

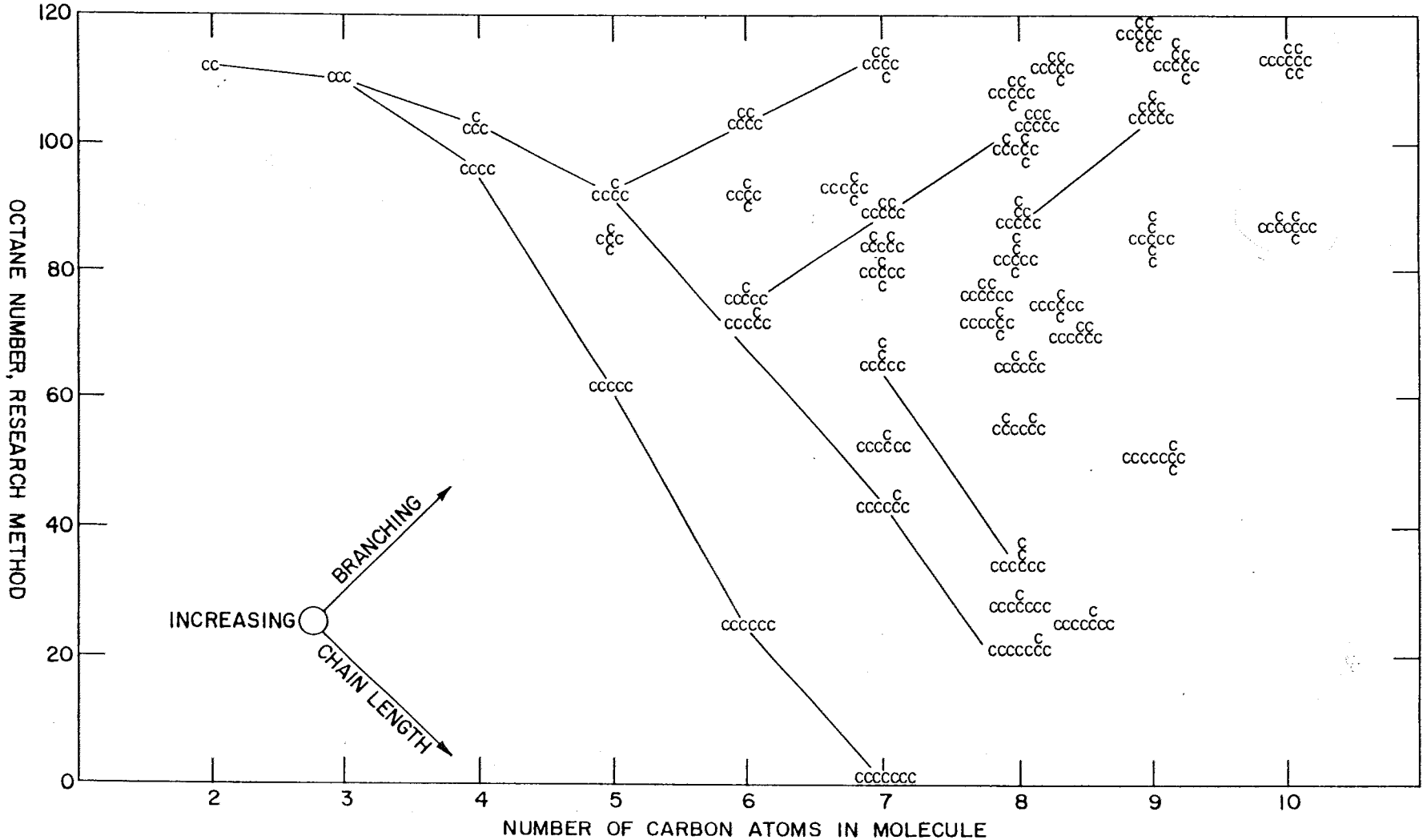


FIG. 3. — Antiknock Level of Paraffins.

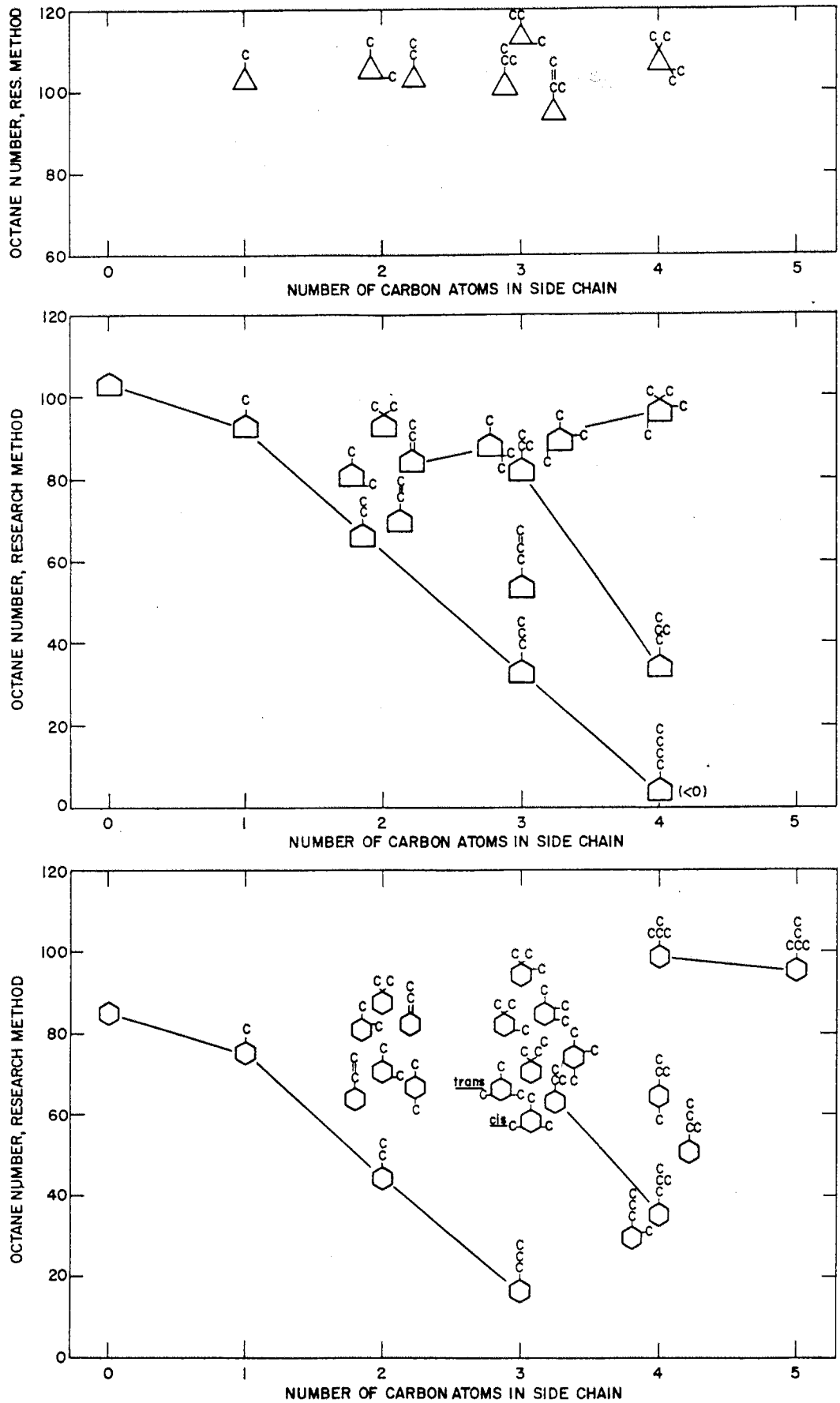


FIG. 5. — Antiknock Level of Cyclic Paraffins.

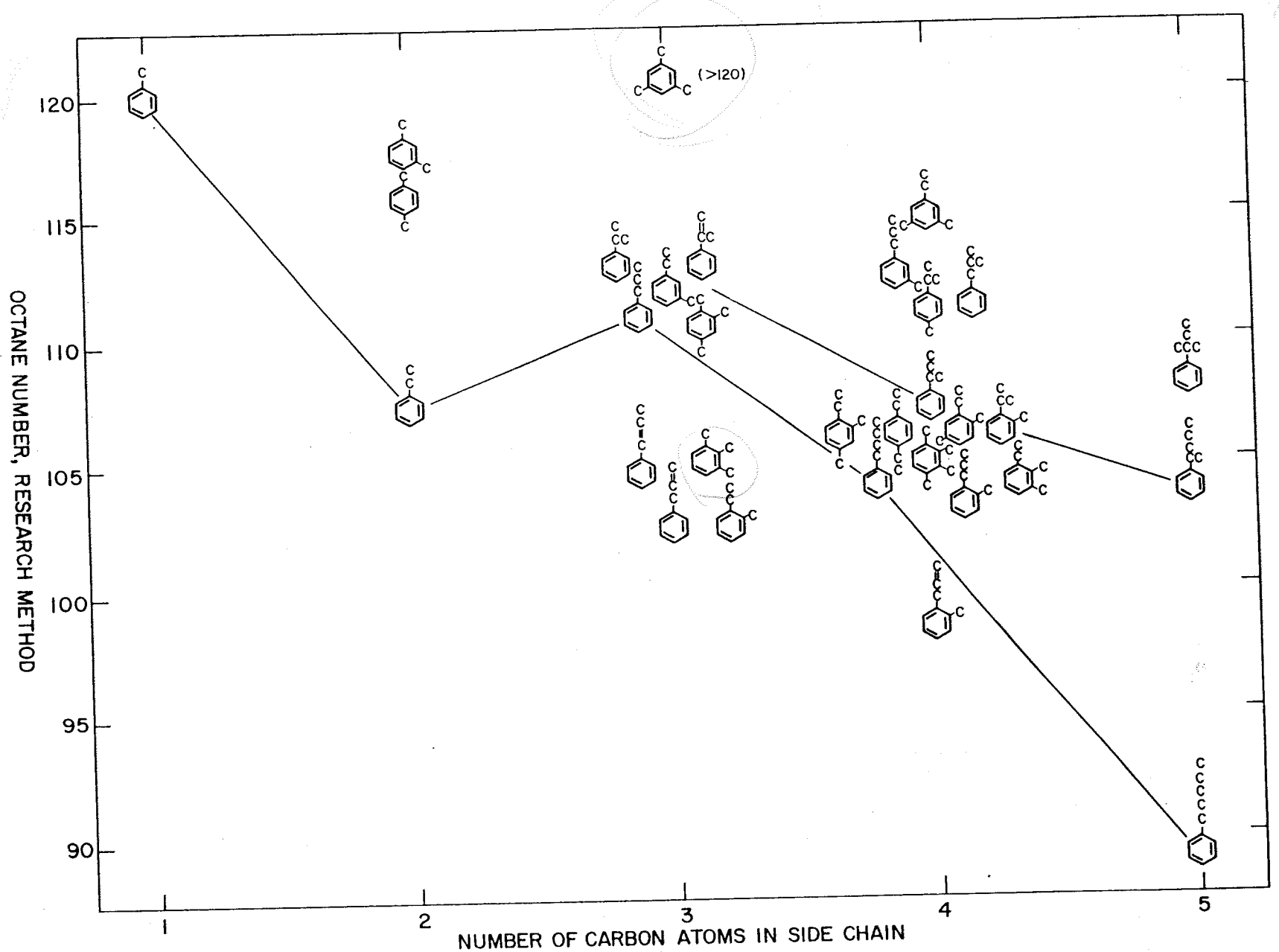
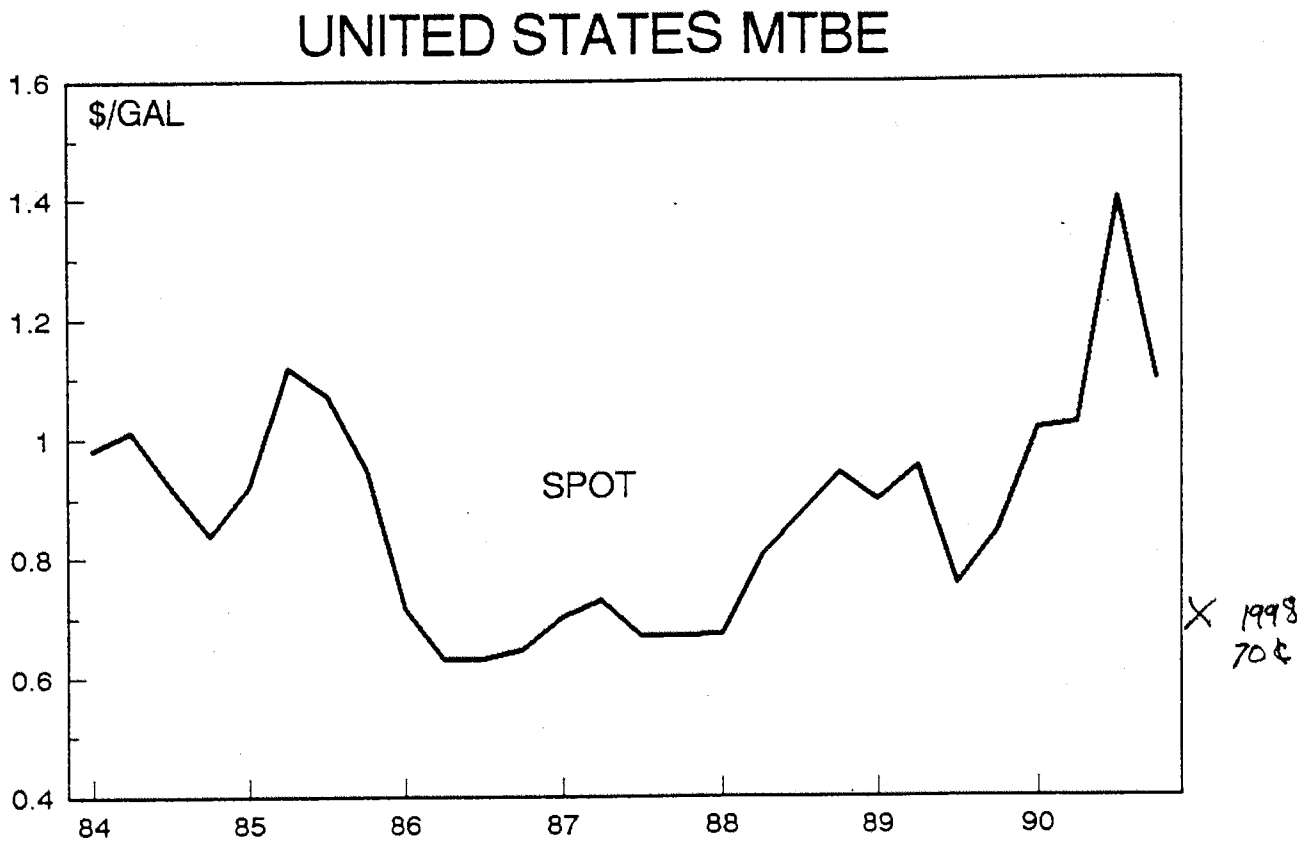


FIG. 6. — Antiknock Level of Aromatics.

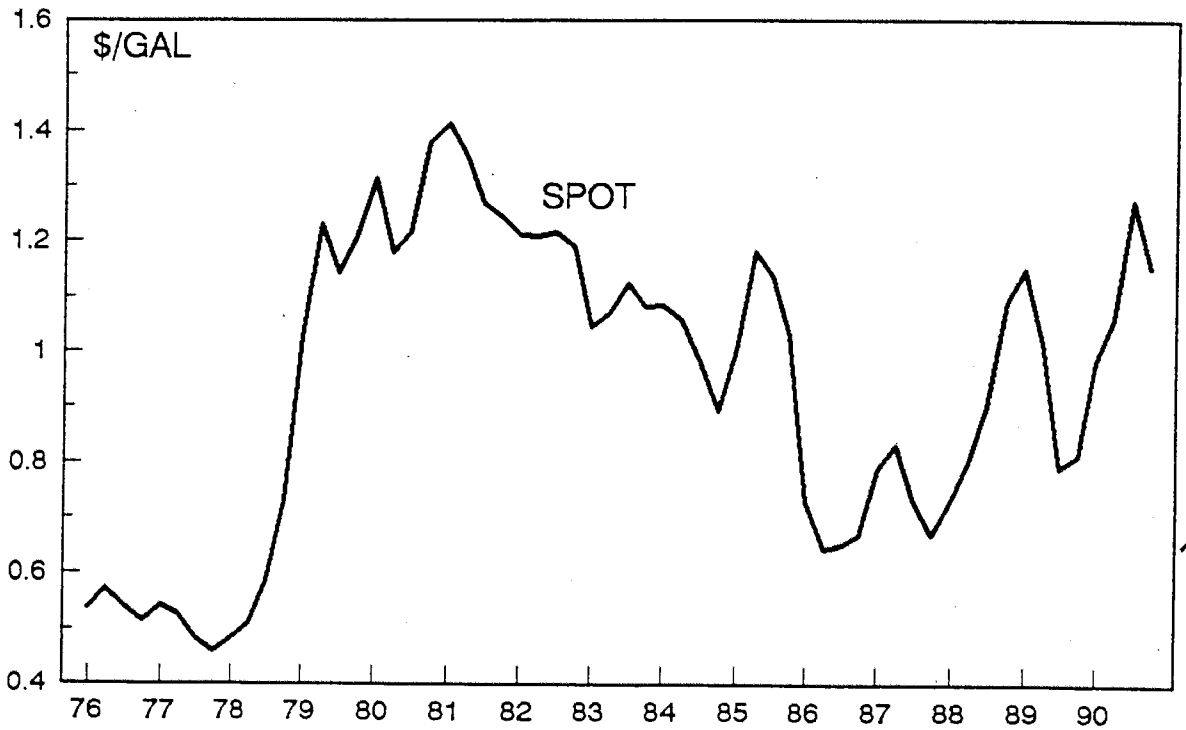

UNITED STATES MTBE
$/GAL
1.6
1.4
1.2
1
0.8
0.6
0.4
SPOT
84
85
86
87
88
89
90
X 1998
70¢

U.S. STYRENE
DeWitt & Company Inc. Historical Pricing
Reported Quarterly

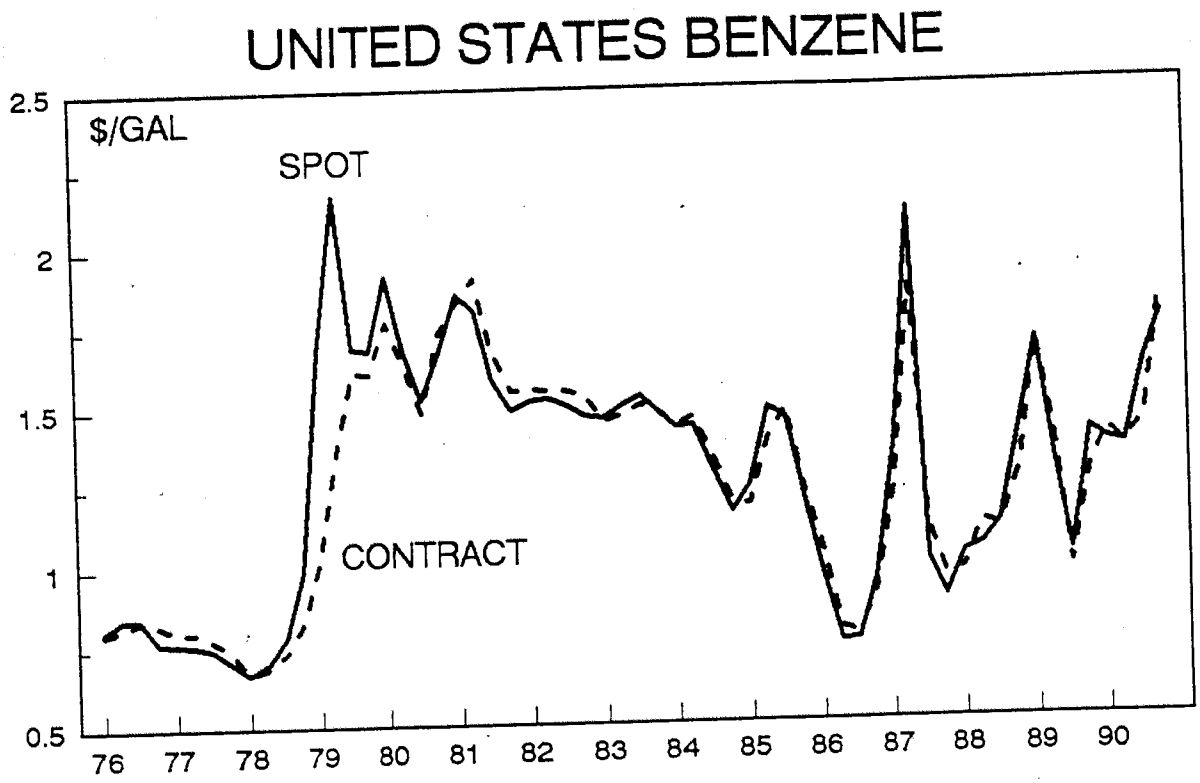
Date	SPOT-$/LB		CONT.-$/LB		SPOT-$/TON		CONT.-$/TON	
	Low	High	Low	High	Low	High	Low	High
1-Qtr. 1976	0.194	0.200	0.201	0.210	428	441	442	463
2-Qtr. 1976	0.205	0.209	0.210	0.210	452	460	463	463
3-Qtr. 1976	0.194	0.196	0.210	0.210	427	432	463	463
4-Qtr. 1976	0.179	0.182	0.203	0.210	395	401	448	463
1-Qtr. 1977	0.173	0.181	0.195	0.205	381	399	430	452
2-Qtr. 1977	0.172	0.173	0.195	0.200	378	382	430	441
3-Qtr. 1977	0.171	0.173	0.193	0.196	376	381	426	432
4-Qtr. 1977	0.162	0.164	0.184	0.200	356	361	406	441

UNITED STATES TOLUENE

COMMERCIAL GRADE

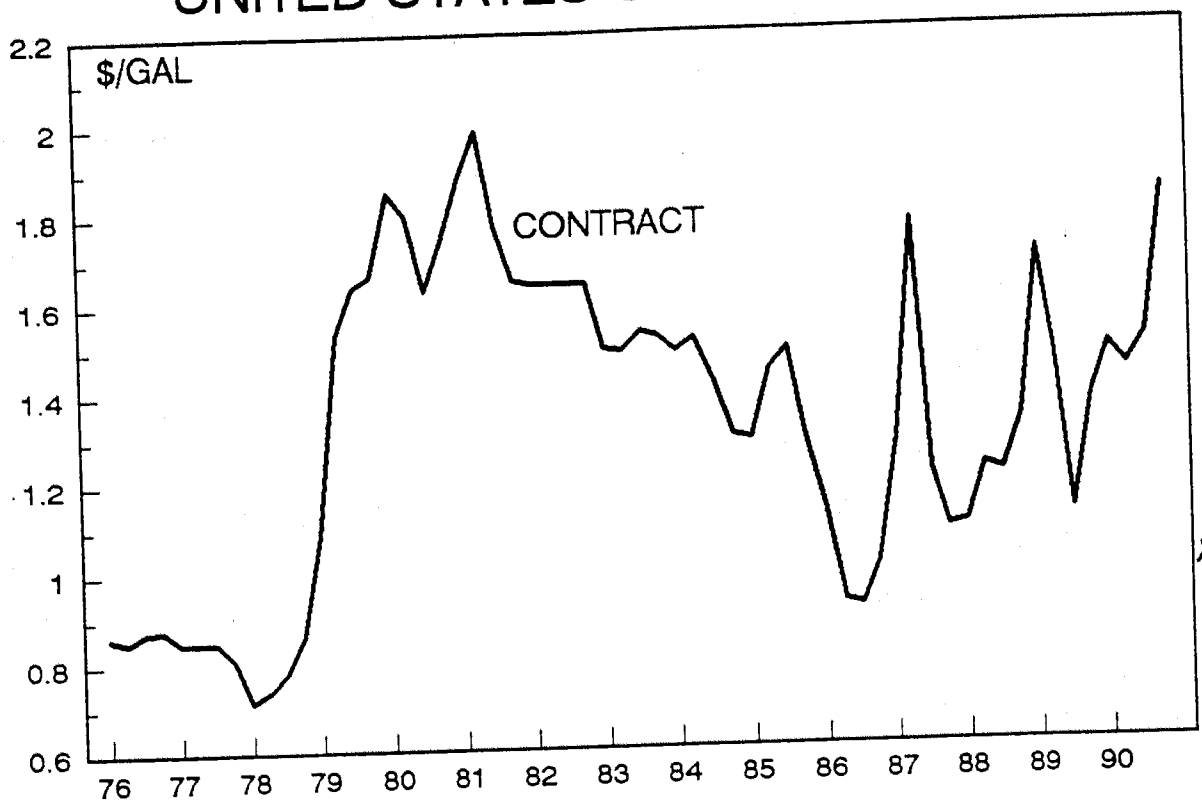


X 1948
0.69


UNITED STATES BENZENE
$/GAL
SPOT
CONTRACT
2.5
2
1.5
1
0.5
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90

x 1998
77¢

UNITED STATES CYCLOHEXANE



x 1994
1.05

non-fuel
- nylon industry
- high grade